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Project Director: Patricia Silence (psilence@cwf.org)

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Final Performance Report

NEH Sustaining Cultural Heritage Collections Planning Grant PF-50269-12

Evaluation of Mechanical and Control Systems Serving the Art Museums at Colonial Williamsburg

Patricia Silence, project director

Colonial Williamsburg Foundation

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Background

The NEH Sustaining Cultural Heritage Collections Planning Grant, “Evaluation of Mechanical and Control Systems Serving the Art Museums at Colonial Williamsburg,” was an exercise in improving museum operations by gaining a better understanding of our complex system that was created, layer by layer, via numerous construction, programming, troubleshooting and repair campaigns. Colonial Williamsburg facilities and conservation staff wanted to evaluate these intricate conditions and plan corrective actions that would maintain an excellent collections environment, save energy and extend the life of our buildings and equipment.

The DeWitt Wallace Decorative Arts Museum was put into service circa 1984, and many of the original mechanical systems and associated controls are still in service, including the main air handlers and heating plant that serves this 79,200-square-foot facility. The flat-roofed brick building’s insulation and vapor barriers are consistent with 1980s construction, and problems with water intrusion above and below ground are being addressed as the building ages. An above ground two-story masonry and frame 13,800-square-foot building, referred to as the Public Hospital, was constructed at the same time as the Wallace Museum. This building serves as the museum entrance and includes a gift shop, a small collections display area, office space, public restrooms and storage. An outside garden area was converted to museum space in 2006 for the new 13,200-square-foot Abby Aldrich Rockefeller Folk Art Museum addition. The Public Hospital and the Folk Art Museum addition are served by air handlers that are connected to the existing Building Automation System (BAS) and the Wallace Museum’s heating and chilled water plants. Included in the 2006 Folk Art Museum project scope was replacement of the Wallace Museum central plant chillers, which serve both museums. Cooling towers and pumps were left in place and are circa 1996. While the exterior shell of the Folk Art addition is brickwork dating from 1984, the structure is well insulated and the vapor barrier provides a very tight envelope.

Given multiple conjoined structures and equipment as well as an older BAS system, it is an understatement to say that HVAC and its controls are complicated for Colonial Williamsburg’s Museums. The Wallace Museum has two variable air volume (VAV) air handlers that distribute air through six humidity control zones and 43 VAV temperature control zones. Relative humidity (RH) for the Folk Art Museum is controlled by chilled water coil dehumidification and steam humidification in each of two constant volume air handlers, distributing conditioned air to 12 zones of reheat. The Public Hospital has one VAV air handler that distributes air to 12 VAV temperature control zones, and one humidity control zone for the collections display area. All air handlers are designed for air side economizer capability, but admitting large quantities of outside air for “free cooling” has at times caused operational and environmental problems, so this operating mode has been discontinued. Presently, dampers are positioned to bring in minimum required outside air, and increased if necessary to reduce carbon dioxide levels. The design sequence of operation at the Folk Art Museum is overly complex and fan tracking controls at the Wallace Museum are outdated and, therefore, have marginal capability. Currently, the mechanical systems run 24 hours per day. We have roughly 1,317 monitoring points at the Wallace Museum, 91 points at Public Hospital and 359 points at the Folk Art Museum.

Monitoring for environmental alarms, equipment failures and power outages is performed at our central Work Control facility, which is nearby but offsite. Changes in equipment programming are made via the Johnson Controls program at this location, not by our two onsite mechanics. Occasionally, this yields longer response time and less efficiency since programmers are unable to witness actual equipment operation. Internal communication, given the size of our campus, can be a challenge.

Using sensors inside the walls of the Folk Art Museum, we have noticed elevated moisture when the HVAC creates negative pressure. In other areas where we have no wall sensors, we have found pests -- square necked grain beetles -- that indicate moisture leading to mold growth, which is a food source for these insects.

As a further complication, we must add an exterior auxiliary chiller in summer, as we do not have permanent equipment sufficient for redundancy during peak cooling seasons. While we do collect data on various zones and equipment operation, it is neither consistent nor easily shared with colleagues.

Project Activities

The work plan for this project originally included five phases. While we anticipated the process to be fairly linear as it progressed, in practice, the phases described below were revisited numerous times as our vision of better operations for Colonial Williamsburg's museum facilities was clarified.

1. Investigative/Scoping

The Investigative/Scoping phase began with collection and review of existing documentation such as drawings, utility bills, maintenance reports, light fixture counts, emails, incident reports, etc. This refreshed Colonial Williamsburg (CW) staff's collective memory and familiarized our consultants, Wiley/Wilson (W/W), with the facility and associated HVAC and lighting equipment. Meetings with W/W included several CW stakeholders including: Rick Hadley (director, Museums), Neil Ellwein (director, Architecture and Engineering), Gene Turner (lead mechanic, Facilities Maintenance), Larry Christian (supervisor, Operations and BAS) and Patty Silence (conservator, Museum Exhibitions and Historic Interiors).

There were several on-site inspections of the equipment and facility, and CW maintenance and Johnson Controls (JC) personnel familiar with the site were important participants in these inspections. CW staff updated a spreadsheet that calculates current watts/square-foot for lighting used in exhibition spaces. Most back-of-house spaces are lit with tube or compact fluorescent fixtures.

The following issues were identified:

- Improper building pressurization was identified and found to be the result of poor supply and return fan tracking associated with inlet vane performance, improper control of relief damper and filter loading effect on supply airflow. Building pressurization is further complicated by the fact that the facility is made up of three buildings conjoined by very large openings between them, resulting in air transfer between buildings.
- Existing BAS is unable to generate BAS logic diagrams to facilitate readily understanding of programmed control sequences. Programming code that could be retrieved from the JC system, requiring assistance at a high cost from our vendor, was not useful, as it was too difficult to analyze and interpret. This inability to readily understand programmed control sequences makes it difficult to improve equipment operation that would result in better efficiency and environmental control.
- Mechanical and environmental monitoring is less than ideal. Personnel from various departments are unable to access the same data for various applications. Long-term trends can be created and shared, but not easily. Each of the CW "stakeholders" would benefit from

automatic downloads and long-term data trends from exhibit spaces and key mechanical equipment.

- Most exhibition spaces are lit with halogen fixtures, some of which do not completely filter out ultra-violet (UV) light, which is particularly damaging to light-sensitive media and unnecessary for viewing collections. Halogen bulbs also produce significant heat.
- Opportunity to decrease humidification set point from 50% RH to 45% RH in order to reduce energy use.
- Opportunity to implement a night setback strategy that shuts down building exhaust fans and closes outside air dampers during unoccupied periods which saves substantial energy and reduces wear on equipment.
- Opportunities to improve central plant equipment at the Wallace Museum were reviewed, but no favorable short term projects were identified. Only short term projects were considered since planning is underway to replace the central plant equipment with new as part of a future museum addition.

2. Concept Development

Concepts for projects that would improve sustainability of our museums site and its environment were developed via discussions between W/W and CW personnel. We considered daily operation and occupation of the facility, constructability of the systems, suitability of the control system to meet museum requirements, and overall projected costs and savings of energy and money. This included consideration of a future facility expansion which, while not imminent, would eventually include construction of a new central plant with boilers, chillers and cooling towers to serve the entire museum complex.

Items for consideration included upgrades that often yield energy savings in contemporary HVAC design and addressed deficiencies that we recognized. These included:

- Purchase of analytical tools (computer programs) that foster communication and translate and make sense of data. This would help us evaluate the collections environment and assess energy savings. Ideally we would like to use controlling sensors, which are calibrated frequently and well placed to get valid information. Johnson Controls offers their Energy Dashboard and Reporting Tool (EDART), which interfaces with the sensors installed throughout the site and displays real-time data. The Image Permanence Institute offers eClimateNotebook, which requires data from sensors to be downloaded into the program. This tool offers preservation metrics and the ability to evaluate conditions based on collections that are housed in a given space.
- Transition to an open-source BAS controls interface that would allow for more in-house control and understanding of how we are operating HVAC equipment.
- Upgrade of our exhibition lighting, which primarily uses halogen lamps, to LED lamps.
- Installation of boiler flue economizers.
- Adjustment of target set points for humidity and/or temperature.
- Implementation of an occupied/unoccupied mode (exhaust fan and outside air adjustment) schedule.

- Implementation of Wallace Museum and Folk Art Museum fan modifications to improve controllability of building pressurization.
- Addition of geothermal wells for peak cooling heat rejection.
- Adjustment of lighting schedules.

3. Analysis/Modeling

Analysis and modeling were done by W/W and helped determine what we could and should do immediately as well as projects to plan for implementation as funding becomes available. They presented options of work to be done, with corresponding payback rates considering projected savings and descriptions of other benefits. A number of projects addressed problems that will likely be corrected when tentative expansion plans are realized, or were too expensive compared to the return in energy savings.

A project to upgrade air handler fans with variable frequency drives (VFDs) and revised relief air damper control to correct building pressurization was projected to save an estimated \$36,000 per year by correcting undesirable infiltration. We plan to use these air handlers in their respective locations for many more years, so improving their performance is a top priority.

A project to replace the outdated, proprietary and soon to be unsupported BAS controllers and operating system for the air handlers and VAV terminals was recognized as key to improving operation of existing equipment. This upgrade would simplify evaluation of programming logic, thereby making it much easier to determine changes that would enhance performance. While it is difficult to determine energy savings resulting from this project, it is clear that it would allow us to improve the operation of air handling equipment that impacts the museum environment.

A couple of projects were shown to be inexpensive, simple to implement and a source of quick and substantial energy savings. This included programming changes to adjust the “humidify-to” set point to 45% and implementing an unoccupied mode outside air schedule. These measures were implemented at a cost of about \$1,200 with annual savings estimated at \$11,700.

Replacement of halogen lamps with LED fixtures was somewhat expensive compared to annual energy and cost savings, in part due to our comparably low energy cost of \$.07/KWH. While payback for this project is projected at over nine years, there are a number of good reasons beyond economics to consider upgrading to this technology, which offers superior color rendering and lighting control excluding UV and infrared exposure. Further, LED lamps last significantly longer than halogen lamps. This yields savings of staff time previously spent replacing failed components.

4. Program Verification

Throughout the planning project all parties agreed that maintaining ASHRAE AA standards for our museum facilities, as CW has for many years, should continue. Once we achieve a high level of efficiency and control, as well as the ability to measure energy use and relate it to environmental conditions, we will be prepared to experiment with adjustments to temperature and RH parameters. At this point we believe that we can and eventually should implement routine equipment shut-downs during unoccupied hours. This requires the addition of VFDs and appropriate motors to each air handler in order to facilitate frequent starts and stops. We will be testing the night shut-down strategy at the Folk Art Museum later in 2014. Program verification continues, as the CW team responsible for this planning project continues monthly meetings to evaluate conditions and resolve problems for the site.

The use of eClimateNotebook and EDART supports these efforts and allows us to measure and report on improvements.

5. Evaluation and Implementation

CW's evaluation of proposed projects is based on best practices for collections and structural assets preservation as well as the cost/benefit analysis of upgrade measures provided by W/W. We were pleased to be able to complete some projects within the time and financial parameters of this Planning Grant. Other projects are now ready to implement as budget and time allow, including the following:

- Improper building pressurization
 - Replace inlet vane dampers on the Wallace Museum's two AHU supply and return fans with VFDs, including new VFD rated motors, (2) 75 horsepower (HP) for supply fans (SFs) and (2) 20 HP for return fans (RFs).
 - Replace inlet vane dampers on Public Hospital AHU supply and return fans with VFDs, including new VFD rated motors, 20 HP SF and 7.5 HP RF.
 - Install (2) 20 HP and (2) 10 HP VFDs on the Folk Art Museum's two AHU supply and return fans.
 - Install new airflow measuring stations in minimum outside sections of the Public Hospital AHU and Folk Art Museum's two AHU.
 - Install new pressure sensor and transducer in relief air duct of the Wallace Museum's two AHU for independent positioning of relief damper.
 - Install down duct pressure sensor and program VFDs on the Folk Art Museum's two AHU to adjust fan speed on this constant volume system as required to maintain constant delivered supply air as filter loading increases.
 - Retain Facility Dynamics Engineering to perform commissioning services to validate proper building pressurization control.
- Outdated Building Automation System
 - Replace outdated Johnson Controls' Metasys Control System with latest generation JC BACnet controllers with Web-based user interface to provide museum-wide update of controls for all air handlers, VAV and CAV terminals, and central plant systems.
 - Have controls contractor test and calibrate communications networks and devices, replacing any found to be defective, and perform verification of sequences of operation for all systems.
 - Retain Facility Dynamics Engineering to perform commissioning services to validate and optimize system sequences of operation.
- Inefficient mechanical and environmental monitoring
 - We have purchased and begun using eClimateNotebook™. We have also purchased and installed Johnson Control's EDART, which is currently set up to track and trend over 300 points, including space conditions, mechanical systems control valves and sensors, and air flow measurements in real time. More points can be added as required. These software tools were paid for with \$10,000 provided for "quick fixes" as part of our Planning Grant award.
 - These tools offer evaluation of the collections environment as well as energy use.
 - Data can be viewed and used by any staff member or contractor who needs it.
 - The data can be used to troubleshoot mechanical system performance and is expected to provide a useful tool to optimize system control parameters and sequences.

- Most exhibition spaces are lit with halogen fixtures, some of which do not completely filter out UV
 - CW exhibition, facilities and conservation staff began investigating the use of LED lights several years prior to this planning project. While CW's payback is not as significant as in some parts of the country, we recognize that this technology offers excellent illumination for museum objects and emits only necessary visible light wavelengths.
 - We have exchanged halogen lamps with LED lamps in several exhibitions with good results and demonstrated energy savings. This practice continues as time and finances allow.
- Opportunity to decrease humidification set point from 50% RH to 45% RH
 - BAS was adjusted to this lower set point, resulting in less activity by zone humidifiers.
 - Reduces wear on equipment.
 - Reduces steam consumption estimated to save \$5,200 per year in natural gas consumption, about a 7% reduction in annual usage. Actual reduction undetermined since no equipment level metering.
- Opportunity to implement a night setback strategy that shuts down building exhaust fans and closes outside air dampers during unoccupied periods.
 - Programming changes were made by the project team to implement throughout the museum, estimated to save \$6,500 per year in energy savings.

Accomplishments

This planning grant has resulted in plans for implementation of projects that will improve our collections environment, extend the life of our mechanical systems -- particularly air handlers, improve mechanical performance and save energy.

CW staff that was responsible for the planning grant has developed a collaborative team and continues to meet regularly to continue improving conditions and mechanical performance at the museum. This group discusses and makes programming changes in addition to addressing repairs and management of issues that impact the collection environment.

Our two new data monitoring programs are in use by this team as well as technicians for the site. These programs offer us an improved overview of the museum environment and its mechanical operations. We now have preliminary drawings and specifications for air handler upgrades-- removing inlet vanes and installing VFDs-- and proposals for replacing our obsolete JC BAS in hand.

After further consideration and in-house analysis, CW decided to move forward with installation of the VFDs on AHU-4 and AHU-5 supply and return fans, and expects to complete this installation in late summer 2014. The conventional starters on these supply fans frequently destroy belts on start-up, which is a strong motivation for promptly moving forward with the VFDs. The soft start VFDs will provide potential to implement night time shut downs of these air handlers, with estimated annual savings of \$21,800. The cost to implement the new drives on these VFD rated motors is estimated at \$10,700.

CW is transitioning to LED lighting for exhibitions. Several more galleries will be re-lamped using this technology in 2014. Lighting upgrades will continue in subsequent years.

Patricia Silence shared information on CW's planning grant process and progress with the International Association of Museum Facilities Administrators at their annual meeting in October 2013. In May 2014 she will convene a full-day session on HVAC projects for collections facilities at the American Institute for Conservation's annual meeting.

Evaluation of the Project

Application for grant funding from NEH was a useful activity, as it required us to define goals, form a team capable of meeting the goals and work together to achieve them. Getting outside input was helpful in determining what was wrong with our equipment and operation of it. Our contract engineers weighed options for fixing problems and improving performance of key equipment that we must continue to use. This process considered future plans for expansion, recognizing that some equipment, while not ideal, would be changed out later.

Continuation of the Project

We plan to install VFDs on air handlers and upgrade BAS controllers throughout the museum. As we use eClimateNotebook and EDART, we will install sub-meters at appropriate locations to measure energy use and equipment performance.

Replacement of motor starters with VFDs for the Folk Art Museum's two AHU, (2) 20 HP supply fans and (2) 10 HP return fans is underway.

Lighting upgrades are underway. A \$50,000 capital expense request to upgrade to LED lamps in a particularly outdated exhibit was approved for 2014.

Long-Term Impact

Planning to improve our collections' environment in a sustainable way will yield preservation and educational benefits for many years to come, relieving some fiscal pressures and using energy wisely. Our mechanical equipment will likely last longer and precious staff time will be saved.

This planning project has clarified CW's vision of what improved performance should look like, as well as what work and funding are necessary to achieve it. We also have a better idea of what we will need when we are able to expand the museum facility, including a new mechanical room with efficient chillers, boilers and cooling towers.